NEEA EVAPORATOR FAN INITIATIVE CASE STUDY
Columbia Reach - Yakima, Washington

Summary

As an energy efficiency measure, a variable frequency drive (VFD) was installed to allow reduced fan speed operation in a 1046 bin controlled atmosphere (CA) room used for storage of golden delicious apples.

The impact of VFD operations during a storage season was monitored. The major test parameters are summarized in Table 1.

Table 1 - Major Test Parameters

Test Characteristic	Initial Conditions	Conditions at the End of CA Holding		
		Control Room Room 28	VFD Room Room 27	Improvement Room 27 - Room 28
Mass Loss (%)	0.00%	3.75%	3.43%	0.32%
Firmness (psig)	15.6	14.8	14.4	-0.4
% Energy Use	N/A	100.0%	23.3%	76.7%

Results from the major test parameters showed:

- Less mass loss in the VFD room
- A decrease in average fruit firmness in the VFD room.
- Substantial energy savings with the VFD versus the full speed constant fan control room.

Economics for a full-scale VFD retrofit project are estimated in Table 2. Installation costs are anticipated to be considerably lower for a full-scale retrofit compared to the field trial installation.

Table 2 - Economics for Full-Scale VFD Retrofit Project

Project Cost VFD Retrofit (10 hp)	Cost Savings per Year			Simple Payback (years)
	Energy	Mass	Total	
$2,000	$1,053	$693	$1,746	1.1

Field Trial Description and Purpose

The VFD installation was performed through the "Evaporator Fan VFD Initiative" a market transformation program sponsored by the Northwest Energy Efficiency Alliance (NEEA) and operated by Cascade Energy Engineering to promote the use of VFDs in refrigerated warehouses.

The purpose of the VFD installation was to demonstrate the energy efficiency of the VFD technology and to determine the impact of reduced airflow operation on the commodity in storage. Pending a positive outcome of the field trail, the technology could then be safely and profitably installed on a full-scale basis.

Field Trial VFD Installation

A 10 hp VFD was installed to regulate fan speed on an evaporator coil providing refrigeration to a CA storage room. The evaporator coil was equipped with three 2 hp fan motors. An input line reactor and a dV/dT output filter were added to provide harmonic and motor protection.

VFD versus Control Room

Two identical rooms were selected for comparison. VFD speed control was employed in room 27. Fans ran at 50% speed after fruit pull-down. In the control room (room 28), full speed fan operation was employed during the entire storage season.

Fruit Selection/Sample Creation

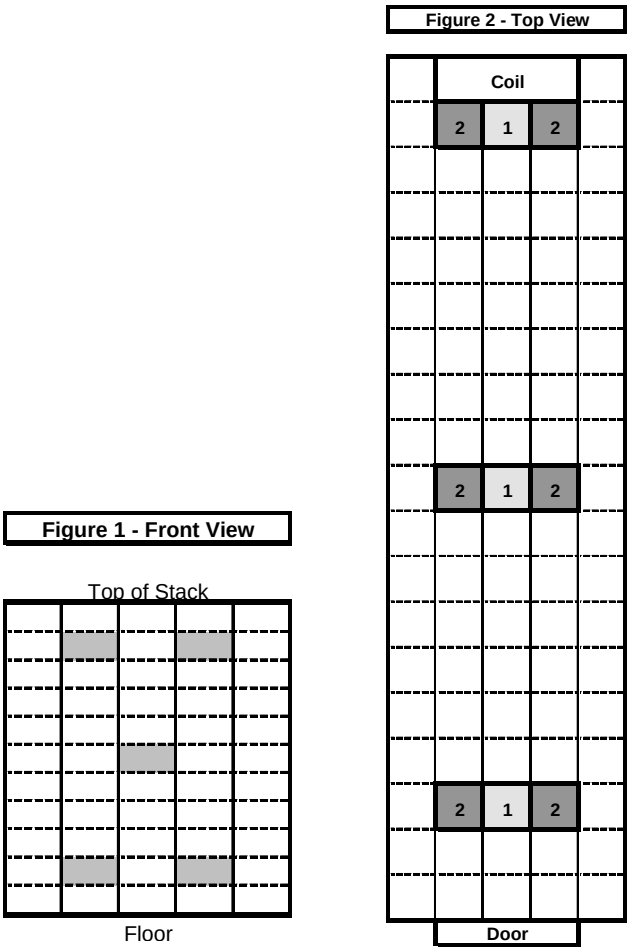
Fruit from a single bin was used to create all test samples. Sample fruit were individually weighed and labeled. Weights were recorded to 1/100th of a gram. 15 sample bags, each containing 8 fruit, were created for each test room. Mesh plastic bags with ~1/2 inch openings were used to minimize the impact on air or moisture flow.

All 30 samples were created during a three hour period. Samples were stored in a covered bin under refrigeration until placed in the proper test location. 30 fruit were sent to a test lab to establish initial fruit conditions.

Sample Placement

Samples were placed in identical locations as the rooms filled. Each sample bag was placed in the center of a bin covered by a layer of fruit. Samples were place in three cross-sections of the room. Five samples were placed in each cross-section as illustrated in Figure 1. The locations of the three cross-sections are illustrated in Figure 2.

Figure 1 - Sample Locations - Front View
Figure 2 - Sample Location - Top View



CA Conditions and Room Loading and Unloading

The VFD and control rooms were maintained at similar temperature, O_2 and CO_2 conditions throughout the storage period.

Table 3 - Room Loading and Unloading

Room Loading and Unloading Information				
Mode of Operation	VFD Room	Control Room	Difference	Storage Advantage
Loadings Days (Non-CA)	10	6	4	Control
CA Holding Days	251	206	45	Control
Unloading Days (Non-CA)	4	4	0	NONE
Total Storage Days	263	214	49	

- The VFD room fruit was stored for 49 more days than the control fruit.
- The VFD room fruit experienced 4 more days of non-CA conditions during the room loading period of the test.
- The differences in the loading and unloading schedules strongly favored the control room. The mass loss improvement seen in the VFD room would have been larger had the loading and unloading schedules been equal.

Sample Retrieval

Test samples were retrieved from test bins as the bins were removed from storage. Individual fruit were reweighed. All samples were then delivered to a lab for further testing.

Mass Loss Results

Evaluation of the mass loss results showed an overall improvement for samples stored in the VFD room.

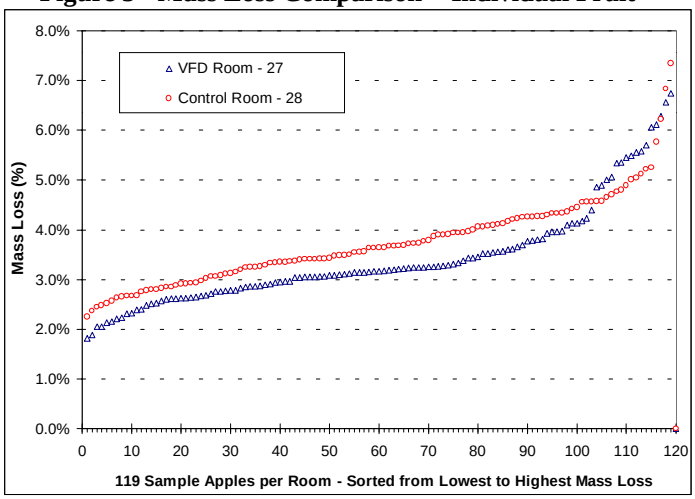
Table 4 - Mass Loss Summary

Sample Location	Mass Loss (%) VFD Room	Control	Improvement
Evaporator End, Lower Left	5.25%	4.30%	-0.96%
Evaporator End, Lower Right	5.72%	4.72%	-0.99%
Evaporator End, Middle	2.95%	3.92%	0.98%
Evaporator End, Upper Left	3.08%	3.61%	0.53%
Evaporator End, Upper Right	2.89%	3.96%	1.07%
Mid-room, Lower Left	3.67%	3.78%	0.11%
Mid-room, Lower Right	2.99%	3.15%	0.17%
Mid-room, Middle	3.09%	3.52%	0.42%
Mid-room, Upper Left	3.09%	3.10%	0.01%
Mid-room, Upper Right	2.83%	3.78%	0.95%
Opposite Evaporator, Lower Left	3.48%	3.99%	0.50%
Opposite Evaporator, Lower Right	3.32%	3.98%	0.66%
Opposite Evaporator, Middle	2.80%	3.78%	0.99%
Opposite Evaporator, Upper Left	3.29%	3.12%	-0.17%
Opposite Evaporator, Upper Right	3.11%	3.57%	0.47%
Total	**3.43%**	**3.75%**	**0.32%**
Evaporator End (5 Samples)	3.98%	4.10%	0.12%
Mid-Room (5 Samples)	3.12%	3.48%	0.36%
Opposite Evaporator (5 Samples)	3.22%	3.70%	0.49%
Upper (6 Samples)	3.04%	3.54%	0.50%
Middle (3 Samples)	2.94%	3.74%	0.80%
Lower (6 Samples)	4.03%	3.97%	-0.06%
Left (6 Samples)	3.65%	3.67%	0.02%
Middle (3 Samples)	2.94%	3.74%	0.80%
Right (6 Samples)	3.43%	3.84%	0.41%

- An average mass loss improvement of 0.32% was recorded.
- 12 of 15 sample sets showed less mass loss in the VFD room.
- In both test rooms, the samples with the greatest mass loss were located near the floor on the evaporator end. The VFD samples in these locations had the greatest mass loss of all samples in both test rooms. These worst case samples were located under the notch in the room created by the mezzanine.

The following figure shows the mass loss improvement for the VFD room on an individual fruit basis.

Figure 3 - Mass Loss Comparison - Individual Fruit



Fruit Firmness Test Results

Results from firmness testing done at the conclusion of CA storage of the test rooms are presented in the following table.

Table 5 – Fruit Firmness Test Results

Sample ID Name	VFD Room - 27 Firmness (psig)	Control Room - 28 Firmness (psig)	Improvement Firmness (psig)
Evaporator End, Lower Left	14.8	14.6	0.2
Evaporator End, Lower Right	15.5	14.0	1.5
Evaporator End, Middle	14.7	14.2	0.5
Evaporator End, Upper Left	13.9	15.3	-1.3
Evaporator End, Upper Right	14.3	15.1	-0.8
Mid-room, Lower Left	14.9	15.0	0.0
Mid-room, Lower Right	14.5	14.7	-0.2
Mid-room, Middle	15.1	14.6	0.5
Mid-room, Upper Left	13.8	15.4	-1.6
Mid-room, Upper Right	13.6	14.7	-1.1
Opposite Evaporator, Lower Left	13.9	14.5	-0.5
Opposite Evaporator, Lower Right	14.4	14.5	-0.1
Opposite Evaporator, Middle	14.4	14.8	-0.4
Opposite Evaporator, Upper Left	14.1	15.5	-1.5
Opposite Evaporator, Upper Right	14.3	NA	NA
Total	**14.4**	**14.8**	**-0.4**
Evaporator End (5 Samples)	14.6	14.6	0.0
Mid-Room (5 samples)	14.4	14.9	-0.5
Opposite Evaporator (5 Samples)	14.2	11.9	2.3
Upper (6 Samples)	14.0	12.7	1.3
Middle (3 Samples)	14.7	14.5	0.2
Lower (6 Samples)	14.7	14.5	0.1
Left (6 Samples)	14.2	15.0	-0.8
Middle (3 Samples)	14.7	14.5	0.2
Right (6 Samples)	14.4	12.2	2.3

- Fruit stored in the VFD room tested 0.4 psig lower in firmness on average than that stored in the control room.
- 4 of 14 sample sets tested higher for firmness in the VFD room.

Energy Savings

Motor current and input power were monitored on the control and VFD room evaporator fans respectively. Energy savings were calculated based on the monitored data.

Figure 4 - VFD Room Input Power

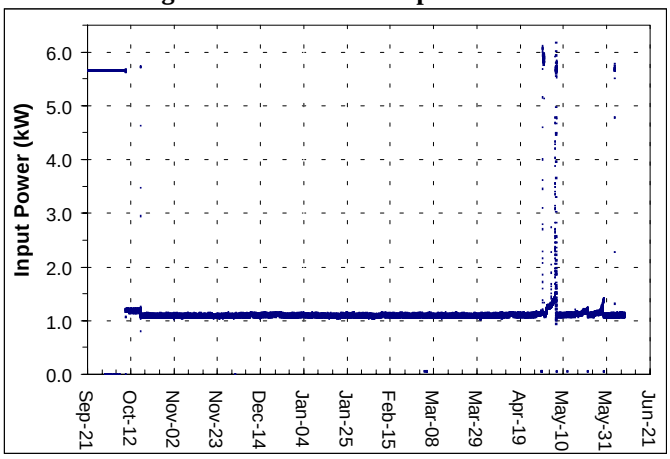


Figure 5 - Control Room Input Power

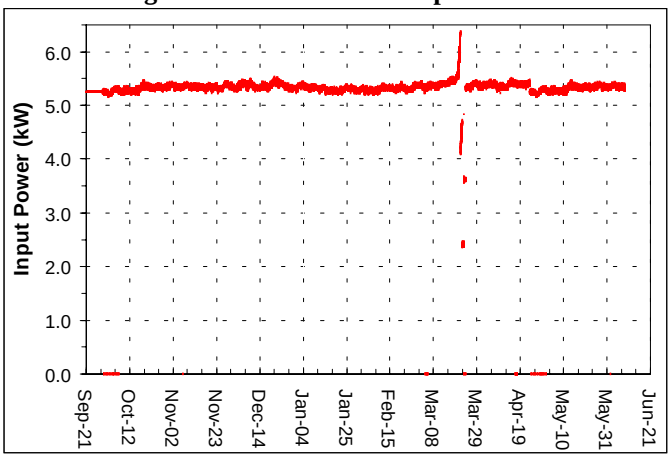
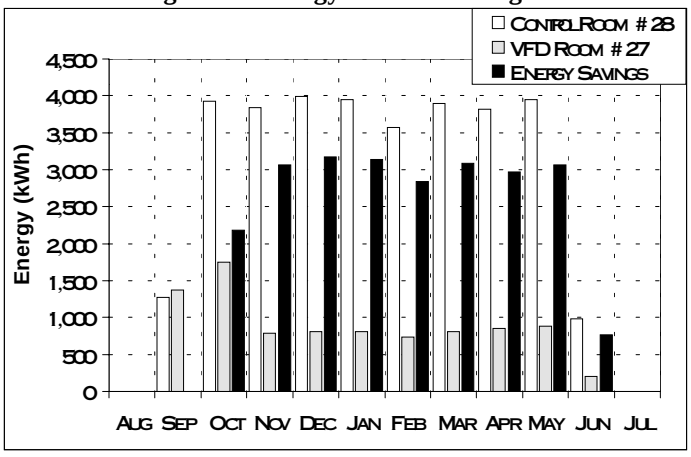


Figure 6 - Energy Use and Savings



- System energy savings of 76.7% were achieved with the VFD.
- VFD input power dropped from ~5.6 kW at 100% speed to 1.1 kW at 50% speed.

Fruit Lab Test Results

The fruit samples were lab tested for the following characteristics.

Table 6 - Lab Test Results

Fruit Characteristic	Initial Conditions	Conditions at the End of CA Holding		
		Control Room Room 28	VFD Room Room 27	Difference Room 28 - Room 27
Soluble Solids	11.2	12.1	12.7	-0.7
Titratable Acid	0.471	0.422	0.425	-0.004

Relative to the control room, fruit in the VFD room was tested to be:

- Higher in soluble solids.
- Higher in titratable acid.

Economic Calculations

The economic calculations are shown in the following table.

Table 7 - Annual Savings Calculations

Bins per Room	1046
lbs. per Bin	900
% Packout	80.0%
Total lbs	753,120
Mass Loss Savings	0.32%
Product Savings (lbs)	2,425
Product Savings (boxes)	58
Product Value ($/box)	$12
Product Value Saved	**$693**
Energy Savings (kWh)	29,647
*Effective Energy Cost ($/kWh)	$0.0355
Energy Savings	**$1,053**
Total Annual Savings	**$1,746**

*Includes Energy and Demand Savings

The VFD installation cost was based on a retrofit project. A new construction VFD installation project would cost ~ 2/3 that of a retrofit project. The simple payback on a similar sized new construction VFD installation would be ~ 0.7 years.